New record of siliceous, marine, later Eocene from Kalbarri, Western Australia

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Abstract

Weathered residue of a previously undetected thin Eocene unit at elevation of 220 m AHD east of Kalbarri includes silicified sponge-rich calcarenite and argillite. Sponges (intact forms and spicules) dominate the silicified fauna but common smaller benthic and planktonic foraminifers, molluscs (gastropods, bivalves, scaphopods, and nautiloids), bryozoans, solitary corals, and serpulid worms are also present. The planktonic foraminifers indicate that the unit lies within the Zone P13 to P16 interval of the Middle to Late Eocene (40.5 – 34.0 Ma BKSA95). In comparison to the Giralia Calcarenite of upper Zone P12, the fossil assemblage indicates that significant cooling in the shallow inner neritic zone apparently took place within the basin during the later Eocene. The ages of known marine Eocene occurrences in the basin, and the contrast between these and underlying formations, indicate major erosion during the interval 53 – 41.5 Ma (late Early to early Middle Eocene) preceding deposition of Zone P12–16 units.

Key words: siliceous, Eocene, Kalbarri, sponges, foraminifers, molluscs, South Carnarvon Basin

Introduction

The marine Eocene in mainland Australia is best known from the southern margin of the continent (McGowran *et al.* 2000; Li *et al.* 2003). Outcrops of such strata in the Southern Carnarvon Basin have been recorded only north of about 26 °S (Fig 1; Haig *et al.* 1997), and have been placed in two formations, the Giralia Calcarenite and the Merlinleigh Sandstone (Condon 1968; Hocking *et al.* 1987). Based on planktonic foraminifers, Haig *et al.* (1997) correlated the lower part of the type section of the Giralia Calcarenite to the upper part of Zone P12 of Berggren & Miller (1988), of Middle Eocene age (about 41.5 – 40.5 Ma according to the BKSA95 time-scale of Berggren *et al.* 1995). Haig *et al.* (1997) interpreted the entire formation at the type locality as the upper transgressive and lower highstand systems tract of one sequence, and suggested that this section represents a limited time interval. Outcrops of the formation at Red Bluff (north of Carnarvon) and Yaringa were correlated with the type section, as was the Merlinleigh Sandstone, although on much more tenuous evidence. Brunnschweiler (1962) had attributed the Merlinleigh Sandstone to the Middle Eocene (upper Cuisian or Lutetian) based on echinoids.

This paper records a new discovery of an Eocene location near the southern margin of the Southern Carnarvon Basin (Fig 1) that is younger than other Eocene localities in the basin, and contains a cooler water fauna. The locality also allows a more precise age to be placed on a major interval of erosion that affected the entire post-breakup basin. Locality details are lodged in the collection register of the E de C Clarke Geology Museum, The University of Western Australia.

Description of site and stratigraphic relationships

The locality lies 27 km east of Kalbarri at about 220 m AHD (Fig 2), and consists of scree dominated by iron-stained siliceous argillites with scattered large fragments of silicified bryozoans as well as large (up to about 30 cm) intact siliceous sponges. A relatively clean sponge-spicule dominated arenite that includes silicified calcareous skeletal grains (including abundant foraminifers, and common gastropods and bryozoan fragments) is also present. The locality extends about 2 km along a low breakaway capped by coarse-grained unfossiliferous silicified and ferrugenised pebbly sandstone probably less than 1 m thick. To the west and south, low exposures of Windalia Radiolarite are present no more than 5 m below the ferrugenised sandstone, thereby setting an upper limit for the thickness of the Eocene at this locality.

Within the scattered rubble of Eocene argillite and silicified calcarenite are pebbles of siliceous porcellinite and silicified belemnite guards (*Peratobelus*) derived from the Late Aptian Windalia Radiolarite (Clarke & Teichert 1948; Hocking *et al.* 1987; Ellis 1993; Haig *et al.* 1996), implying that the Eocene lies unconformably on this Cretaceous unit. The Eocene unit is not formally named because no *in situ* outcrop is present; only the weathered residue of the unit remains at the studied locality.

Eocene fossil assemblage and correlation

All fossils recovered from the site are silicified or were originally siliceous (*e.g.* sponges). Some of the original calcareous skeletons are chalcedonic internal moulds (*e.g.*

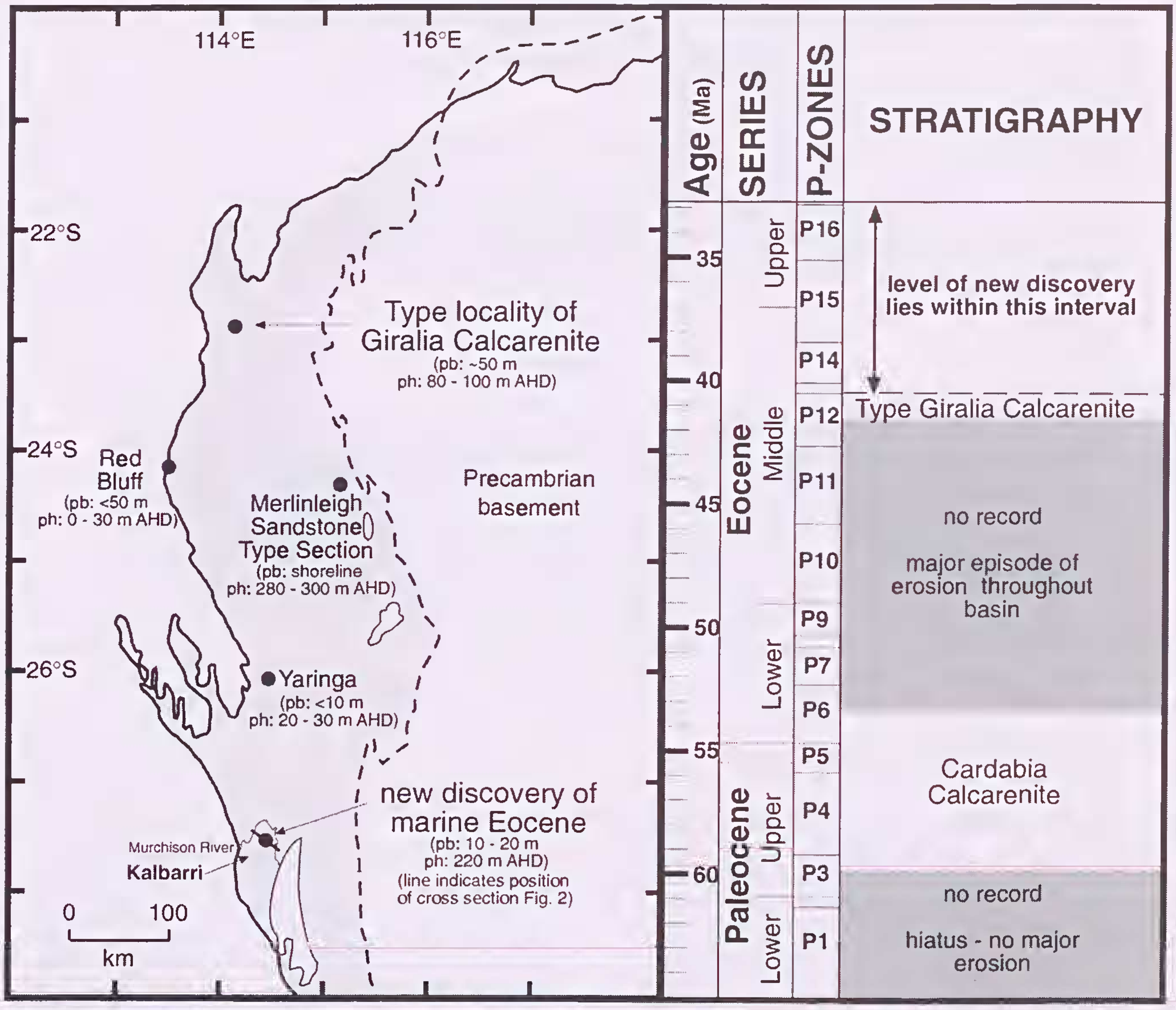

Figure 1. Known outcrop localities of the marine Eocene in the Southern Carnarvon Basin, and the stratigraphic position of the newly discovered unit with respect to other Paleocene–Eocene units known in the basin. pb = palaeobathymetry; ph = present height. The chronometry, series correlations, and P-Zones follow Berggren & Miller (1988) and Berggren *et al.* (1995).

nautiloids and some gastropods); in others the skeleton has been replaced by silica, and chalcedony has in-filled internal cavities. While silicification has preserved the overall morphology, most fine morphological details and microstructure have been lost. The rock samples show that silicification was pervasive as all carbonate grains are replaced and preserved as either casts or moulds.

Demosponges are the most abundant fossils, and are represented by well-preserved intact skeletons, up to 30 cm across, as well as spicules. Bryozoans are diverse and include encrusting types as well as fragments of free specimens. Among the molluscs are common high-spired gastropods, ornamented and smooth bivalves (most equivalved with valves intact), scaphopods, and a few nautiloids including *Aturia* sp (Fig 3Q,R) and an unidentified nautiloid with very gently curved septa (Fig 3S,T). Serpulid worms are encrusted on other macrofossils. Among the microfossils, apart from the prolific sponge spicules, foraminifers are abundant and

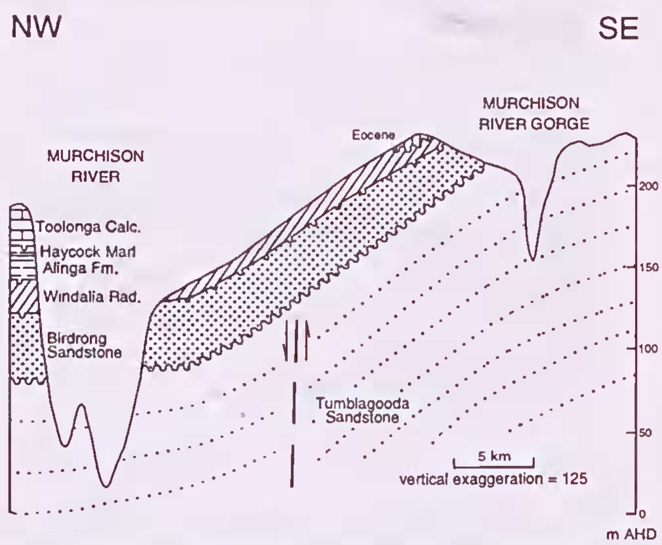

Figure 2. Schematic NW-SE cross-section through new locality showing stratigraphic relationships. The line of section is shown on Fig 1.

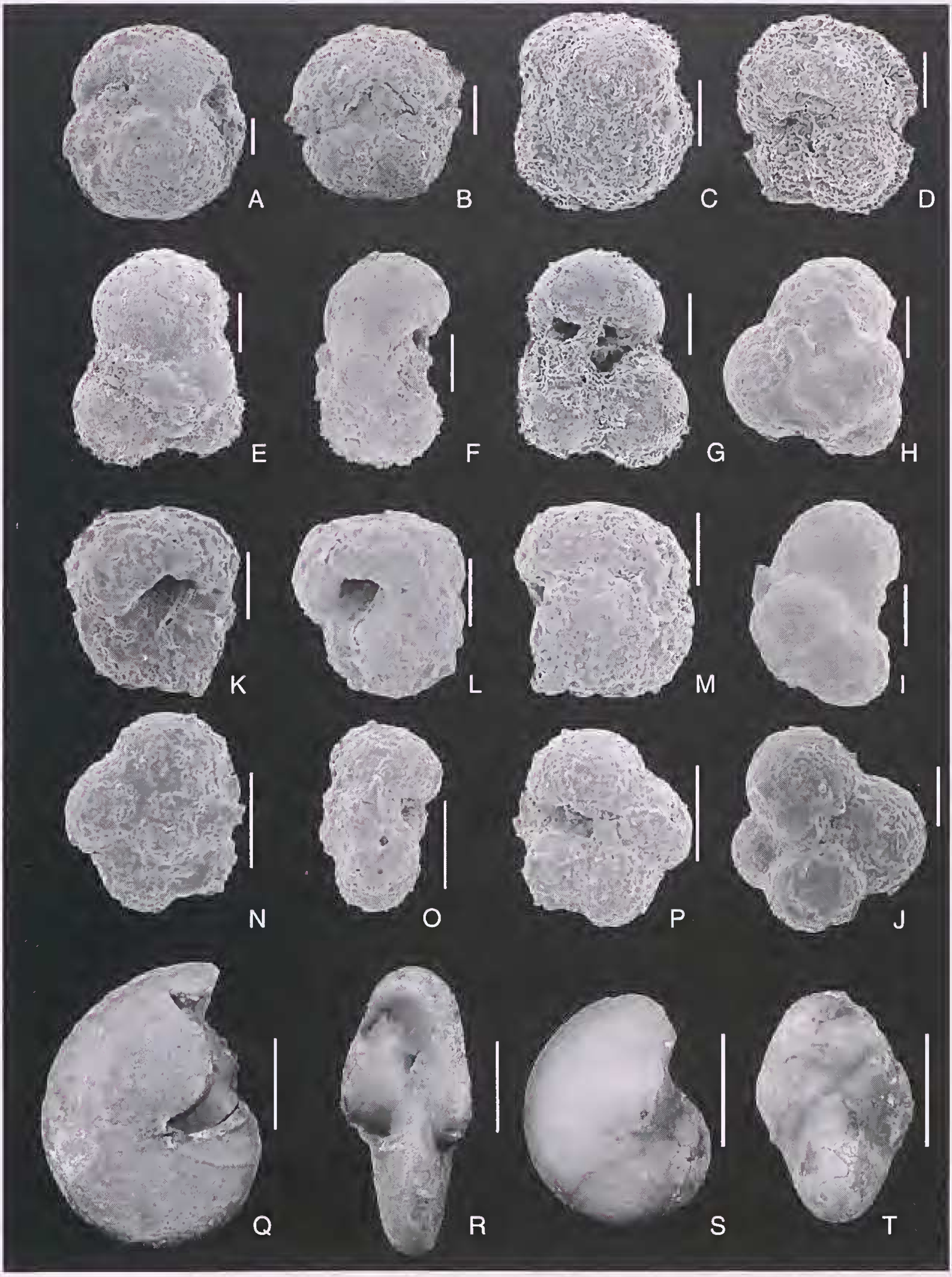

Figure 3. Key fossils for age determination, preserved as siliceous casts. A–P; Planktonic foraminifers (bar scales = 0.1 mm; secondary electron images). A, B; *Globigerinatheka index* (Finlay), lateral views of different specimens, A UWA132079, B UWA130882. C; *Catapsydrax*? sp, umbilical view with umbilicus covered by bulla, UWA130883. D; *Subbotina linaperta* (Finlay), umbilical view, UWA130884. E–G; *Subbotina inaequispira* (Subbotina), spiral, peripheral, and umbilical views of same specimen, UWA130885. H–J; *Subbotina eocaena* (Gümbel) transitional to *S. corpulenta* (Subbotina), spiral, peripheral and umbilical views, UWA130886. K–M; *Turborotalia*? sp possibly from *T. cerroazulensis* lineage, umbilical, peripheral and spiral views, UWA130887. N–P; *Acarinina*? sp, spiral, peripheral and umbilical views, UWA130888. Q–T; Nautiloids (bar scales = 1 cm); reflected light micrographs. Q, R; *Aturia* sp, lateral and peripheral views, UWA130880. S, T; nautiloid indet, lateral and peripheral views, UWA130881.

dominated by benthic types of the Orders Rotaliida (including *Cibicidoides*, *Gyroidinoides*, *Planogypsina*) and Miliolida (including *Quinqueloculina*, *Triloculina*, *Pyrgo*). Less common agglutinated foraminifers (including *Textularia*) and species of the Order Buliminida are also present. Planktonic foraminifers form about 10% of the foraminiferal assemblage. Ostracods make up a small percentage of the microfossil assemblage.

Of the fossil groups present, the planktonic foraminifers provide the best indication of age, and key species are illustrated in Fig 3. The recovered assemblage includes none of the species that define Berggren & Miller's (1988) zonation for the tropical and subtropical Eocene. However, the range charts provided by Toumarkine & Luterbacher (1985) linked to the P-zonation of Berggren & Miller (1988; rather than to the P-zones listed by Toumarkine & Luterbacher) are useful in broadly defining an age for the present material based on international criteria. *Globigerinatheka index index* is recognized by its distinctive coiling, high-arched apertures and incised sutures (Fig 3A,B). According to the compilation of Toumarkine & Luterbacher (1985), this subspecies ranges from Zone P11 to the lower part of Zone P16 (Upper Eocene) and sporadically higher to the top of Zone P17 (the Eocene–Oligocene boundary according to Berggren & Miller 1988). The presence of common *G. index index* therefore indicates that the new unit lies no higher than Zone P16. *Subbotina inaequispira* (Fig 3E–G) ranges from within Zone P7 to uppermost Zone P12. According to Berggren & Miller (1988, p 373) it may range into Zone P13. *Subbotina eocaena* ranges consistently from within P10 to the Oligocene, with descendant *S. corpulenta* ranging from the base of P13 into the Oligocene. The recovered specimens (Fig 3H–J) seem transitional between *S. eocaena* and more high-spired *S. corpulenta*, and imply that the new unit lies within or above Zone P13. The specimen illustrated in Fig 3K–M is a robust low trochospiral form with 3.5 chambers in the final whorl and with chambers elongated in the direction of coiling. The aperture seems to be a relatively high arch from the umbilicus toward the periphery. The wall is deeply corroded, but was probably coarsely perforate. It some aspects, it resembles *Acarinina primitiva* (Finlay) which ranges from the Paleocene to the top of P13 (according to Toumarkine & Luterbacher 1985) and to the 39.0 Ma BKSA95 datum level. More probably, because of its looser coiling and higher arched aperture directed more to the periphery, it belongs to the *Turborotalia cerroazulensis* lineage as outlined by Toumarkine & Luterbacher (1985). The broad peripheral margin shows that the specimen is closer to *T. cerroazulensis pomeroli* than to the more advanced *T. cerroazulensis cerroazulensis*, which has an angled periphery. According to Tourmarkine & Luterbacher (1985), *Turborotalia cerroazulensis pomeroli* is the most abundant and widespread of the subspecies of the *T. cerroazulensis* lineage and ranges through Zones P12 to P17 (Middle to Upper Eocene). Among the other planktonic foraminifers, the specimen tentatively referred to *Catapsydrax* (Fig 3C) has a distinct bulla across the umbilicus and possibly a spinose surface, and may be related to *Catapsydrax echinatus* Bolli of the Middle Eocene (following Stainforth *et al.* 1975). *Subbotina linaperta* (Fig 3D) is a long-ranging species, and the species designation of *Acarinina?* sp (Fig 3N-P) is uncertain and its generic attribution tentative.

Collectively, the planktonic foraminifers indicate that the newly discovered site belongs within the P13 to P16 zonal range (40.5 – 34.0 Ma BKSA95). The absence of zonal index species that would narrow the stratigraphic range may indicate environmental constraints. Distinctive species of *Truncorotaloides*, that are abundant in the upper Zone P12 assemblage from the type Giralia Calcarenite (Haig *et al.* 1997) and range elsewhere to the top of Zone P14, are absent from the new assemblage. *Morozovella*, which also ranges upward to the top of Zone P14, is absent from the new assemblage and from the Giralia Calcarenite P12 assemblage. Two explanations may account for the absence of these genera in the new assemblage: (1) the environment was too cool or too shallow for these genera (see discussion below on independent evidence for a cool shallow-water environment); (2) the new assemblage may belong to a level higher in the Upper Eocene than Zone P14.

Comparison with known Eocene in Southern Carnarvon Basin

The fossil assemblage from the new locality differs substantially from other Eocene assemblages in the Southern Carnarvon Basin (Appendix 1), especially as photozoan benthic faunal elements that characterize warm waters (using the definition of James 1997) are absent. These include "larger" (complex) benthic foraminifers that are abundant in the Giralia Calcarenite type section, at Red Bluff (north of Carnarvon) and Yaringa, and hermatypic colonial corals that are common in the Merlinleigh Sandstone. In contrast, sponges have not been recorded previously from Eocene localities in the basin, but are dominant at the newly discovered site. In this respect, the new unit resembles the Plantagenet Group of the Bremer and Eucla Basins on the southern margin of Western Australia (Gammon *et al.* 2000).

Because of the abundance of robust diverse miliolid foraminifers and the low planktonic percentage (about 10%), the new unit probably accumulated in inner neritic conditions (following Murray 1991), at water depths between about 10 and 30 m (based on unpublished observations of DW Haig for present-day assemblages along the Western Australian coast). This appears to be shallower than for the lower part of the Giralia Calcarenite type section (about 50 m water depth according to Haig *et al.* 1997), but deeper than for the Giralia Calcarenite at Yaringa and for the Merlinleigh Sandstone (see Fig 1). Based on the deduced water depth, the new unit should contain skeletal material belonging to groups such as larger benthic foraminifers, colonial corals, or coralline algae, if it is coeval with the Giralia Calcarenite and Merlinleigh Sandstone. Their apparent absence, however, implies that it is somewhat different in age to these units.

Discussion

The faunal composition of the new unit implies that climatic cooling in the Southern Carnarvon Basin took place during the later Eocene after about 40.5 Ma (BKSA95). McGowran *et al.* (2000) recorded a similar cooling for the later Eocene in southern Australian basins, but the foraminiferal assemblage recovered from Kalbarri does not allow a precise correlation with the southern Australian cooling events. The interregional correlations may only be confirmed by study of thicker, better preserved sections of the Eocene on the North West Shelf (see Apthorpe 1988), if continuously cored sections become available there.

The new discovery adds to knowledge of the erosion history of the basin prior to 41.5 Ma. Erosion of between 25 and 250 m of Cretaceous, and possibly also Paleocene and lower Eocene strata, is estimated to predate deposition of the shallow-water Eocene. The lower estimate is based on the thickness of the Cretaceous Alinga Siltstone and Toolonga Calcilutite preserved below calcrete on the Pillawarra Plateau 22 km north-west of the new location. The upper estimate is based on the maximum thickness of the Toolonga Calcilutite and overlying Cretaceous and Paleocene units further north in the basin. Below the type section of the Giralia Calcarenite, all units down to the Windalia Radiolarite were deposited in mid- to outer neritic settings on a broad, gently inclined continental shelf. The facies in these units are laterally uniform and, although there are hiatuses within the Cretaceous to Paleocene succession, they do not indicate major erosion even though the thicknesses of the units vary (*e.g.* see Dixon *et al.* 2003a, b).

Zones P12–P16 (including outcrops of the Giralia Calcarenite, the new unit, and the Merlinleigh Sandstone) encompass a variety of depositional settings in the Southern Carnarvon Basin (Fig 1). Sediment deposited at that time overlies lowest Eocene at the type section of the Giralia Calcarenite (Haig *et al.* 1997); Campanian (Upper Cretaceous) at Yaringa (Belford 1960); Lower Permian at the Merlinleigh Sandstone type section (Condon 1968); and Aptian (Lower Cretaceous) at the new locality. This implies a significant episode of erosion in the basin during the late part of the Early and early part of the Middle Eocene (about 53 Ma to 41.5 Ma BKSA95). The differences in present heights of the Eocene units in the Southern Carnarvon Basin (see Fig 1) are probably the result of late Neogene uplift, which also elevated underlying Cretaceous strata at the new site by about 60 m relative to the position of equivalent units on Murchison House Station, 22 km to the northwest (Fig 2).

Whatever caused the Early to Middle Eocene erosional event in the Southern Carnarvon Basin also affected the southern margin basins (as there is no record for most of this interval in southern or continental Australia, according to McGowran *et al.* 2000). Coevally, along the northern margin in the Papuan Basin and on the southern Papuan Peninsula there was a change from Cretaceous–Paleocene generally deep-water uniform calcareous mudstone facies to diverse inner neritic Middle Eocene shallow-water limestones (Haig *et al.* 1993).

The three main conclusions that arise from the new discovery are;

1) the new unit, which was deposited in the shallow inner neritic zone, represents the youngest known Eocene in the Southern Carnarvon Basin, and appears to belong within planktonic foraminifera Zones P13 to P16 of Middle to Late Eocene age (40.5 – 34.0 Ma BKSA95);
2) significant cooling within the basin apparently took place during the later Eocene after 40.5 Ma; and
3) a major episode of erosion is inferred during the 50 – 41.5 Ma interval (late Early to early Middle Eocene) preceding deposition of the Middle Eocene units.

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Appendix 1

Fossil assemblages previously recorded from the Eocene of the Southern Carnarvon Basin. Localities are shown in Fig 1.

A. Type section of Giralia Calcarenite, Giralia Anticline

"Smaller" Benthic Foraminifera: Species belonging to the agglutinated Foraminifera *Dorothia*, *Gaudryina*, *Pseudoclavulina*, *Semivulvulina*, *?Spirotextularia*, *Textularia*, *?Uvigerinammina*; Order Lageniida, *Astacolus*, *Dentalina*, *Favulina*, *Globulina*, *Guttulina*, *Laevidentalina*, *Lagena*, *Lenticulina*, *Palmula*, *Pyramidulina*, *Ramulina*, and *Vaginulina*; Order Buliminida, *Angulogerina*, *Brizalina*, *Globocassidulina*, *Kolesnikovella*, *Loxostomina*, *Reussella*; Order Rotaliida, *Alabamina*, *Amphistegina*, *Anomalinoides*, *Asterigerinata*, *Astrononion*, *Cibicides*, *Elphidium*, *Epistominella*, *?Glabratella*, *Gyroidinoides*, *Maslinella*, *?Neoeponides*, *Nonionella*, *Operculina*, *Pijpersia*, *Planorbulinella*, *Pullenia*, *Sherbornina*, *Stomatorbina*, *?Valvulineria* (illustrated by Haig *et al.* 1997)

"Larger" Benthic Foraminifera: Species belonging to Order Rotaliida *Asterocyclina*, *Discocyclina*, and *Nummulites* (Edgell 1952; Cockbain 1978); and Order Miliolida *Alveolina* (Edgell 1952)

Planktonic Foraminifera
Species attributed to upper part of Zone P12 of the Middle Eocene: *Acarinina primitiva* (Finlay), *A. senni* (Beckmann), *A. bullbrooki* (Bolli), *A. collactea* (Finlay), *A. pseudotopilensis* Subbotina, *Globigerinatheka kugleri* (Bolli, Loeblich & Tappan), *Globigerinatheka subconglobata subconglobata* (Shutskaya), *Guembelitrioides* sp. cf. *G. higginsi* (Bolli), *Hantkenina* sp *cf H. australis* Finlay, *Pseudohastigerina micra* (Cole), *Subbotina frontosa* (Subbotina), *Truncorotaloides topilensis* (Cushman), and *Truncorotaloides rohri* Brönnimann & Bermúdez (Haig *et al.* 1997)

Nautiloids
Species including: *Aturia* sp *cf A. clarkei* Teichert, *Aturoidea brunnschweileri* Glenister, Miller & Furnish; *Teichertia prora* Glenister, Miller & Furnish (Glenister, Miller & Furnish 1956)

Other skeletal debris observed in thin section (Haig *et al.* 1997)
Bryozoans; echinoids; coralline algae; *Distichoplax* algae

B. Giralia Calcarenite at Red Bluff

Benthic Foraminifera
"Larger" calcareous hyaline species (Order Rotaliida): species belonging to *Asterocyclina* and *Discocyclina* (Cockbain 1978)

Planktonic Foraminifera
Globigerinatheka and morphotypes of the *Acarinina–Truncorotaloides* complex (Haig *et al.* 1997)

Other skeletal debris observed in thin section (Haig *et al.* 1997)
Bryozoans

C. Giralia Calcarenite at Yaringa

Benthic Foraminifera
"Larger" calcareous hyaline species (Order Rotaliida): species belonging to *Discocyclina* and *Asterocyclina* (Cockbain 1978)
Other benthic foraminifera: smaller Rotaliida including *Cibicides*; rare agglutinated and buliminid species (Haig *et al.* 1997)

Planktonic Foraminifera
?Acarinina and *Subbotina* (Haig *et al.* 1997)

Other skeletal debris observed in thin section (Haig *et al.* 1997)
Bryozoans, echinoids, molluscs

D. Type section of Merlinleigh Sandstone

Benthic Foraminifera
Calcareous hyaline benthic species (Order Rotaliida): species of *Maslinella*, *Crespinina*, *Operculina*, *Rotalia* (Cockbain 1981)

Nautiloids
Aturia clarkei Teichert (Teichert 1944)

Other fossil groups
Colonial corals (species of *Cyphastrea*, and *Duncanopsammia* according to Pulley 1959); hydrozoans (*viz Millepora* according to Pulley 1959); echinoids (species of *Cyamidia* and *Lenicyamidia* according to Brunnschweiler 1962); molluscs (Condon 1968); bryozoans (Cockbain 1981); leaf fossils, teredine-bored wood, and *Banksia* fruiting bodies (McNamara & Scott 1983)